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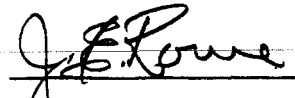
AN INVESTIGATION OF NONLINEAR INTERACTION PHENOMENA IN THE IONOSPHERE

This report covers the period December 1, 1964 to June 1, 1965

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REPORTS ISSUED DURING THE LAST PERIOD

H. C. Hsieh, "Review on Radio Noise of Natural Origin", Tech. Report No. 82; February, 1965.

H. C. Hsieh, "Thermal Radiation from the Ionosphere", Tech. Report No. 84; April, 1965.

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1. General Introduction

The overall objective of this research investigation is to study such ionospheric phenomena as thermal radiation noise, the propagation of naturally occurring radio noise through the ionosphere and the generation of VLF emissions. In particular, various traveling-wave interaction mechanisms are being studied in order to determine their applicability in explaining various ionospheric phenomena such as indicated above.

Many of the phenomena of interest involve the interaction of drifting streams of charged particles and electromagnetic waves, including the excitation of electrostatic plasma oscillations and cyclotron wave interactions. Since many of these phenomena are nonlinear it is reasonable to apply the nonlinear methods of analysis used on TWT's and beam-plasma interactions to their study. The two nonlinear methods being used are a Lagrangian particle analysis and one in which the nonlinear collisionless Boltzmann equation is solved by a moment expansion method.

The following sections of this report outline the particular problems presently being investigated. The research activities during the period from December, 1964 to June, 1965 have been concerned with the study of the thermal radiation from the ionosphere and the traveling-wave amplification process in connection with VLF emissions.

## 2. Study of Thermal Radiation (Noise) from the Ionosphere

2.1 Development of a Theory of Ionospheric Thermal Radiation. A theory of ionospheric thermal radiation has been developed based on a linear macroscopic fluctuating electromagnetic field theory with the aid of the Maxwell and Langevin equations. The ionosphere is considered to be a dissipative medium in which the random thermal motions of the charged particles act as a source of thermal radiation. Attention has been focused on the process of electrons colliding with ions and neutral particles in the ionosphere. Based on the superposition principle, general expressions have been derived from  $w(f, V_s)$ , the thermal noise power generated per unit bandwidth from any given source region  $V_s$  of the ionosphere, and for  $P_o(f, V_s)$ , the available thermal noise power per unit bandwidth at a receiving antenna. No restriction is imposed on the frequency range for these expressions, which are valid for most regions of interest in the ionosphere where the electron collision process plays a major role in the development of thermal radiation.

The results of this study have been reported in Technical Report No. 84 entitled "Thermal Radiation from the Ionosphere".

2.2 Characteristics of Ionospheric Thermal Radiation. Based on the above theory, a theoretical investigation of the characteristics of ionospheric thermal radiation has been made with the aid of experimentally observed available data for the profile of the electron number density. The spectral distribution of ionospheric thermal radiation has been obtained. A study of the calculated power level of the thermal noise generated in the ionosphere shows that it is exceedingly low and decreases with an increase of frequency  $f$  rather rapidly. A large portion of the noise generated appears to be in the frequency range of  $f < 10^7$  cps, with the microwave noise signal being negligible, and appears to come mainly from the region

between 60 km and 100 km height of the ionosphere. Furthermore, the study shows that the available noise power at a receiving antenna depends upon the geographical location of the antenna in general and its power level is higher in the equatorial zone than in the polar cap zone. The results of the present study will be submitted to a technical journal for publication.

It should be pointed out that the present analysis is not as rigorous as a microscopic treatment using the Boltzmann transport equation with the proper collision integral, which will be considered in a future work. However it does offer a simple and direct way of analyzing the thermal radiation from an anisotropic ionized medium and thus it should serve as a useful step toward understanding the process of ionospheric thermal radiation.

### 3. Traveling-Wave Amplification Process in Relation to VLF Emission

3.1 A Necessary Condition for Wave Amplification Under Small-Signal Conditions. Because of the fact that the ionospheric plasma in the presence of the earth's magnetic field can act as an effective slow-wave structure for a traveling wave, while a corpuscular stream discharged from the sun may be assumed to provide the required beam, the Pierce<sup>1</sup> theory of traveling-wave amplification, developed primarily for a laboratory TWT, has been applied by various workers<sup>2,3</sup> to the study of some ionospheric phenomena. For example, the TWT amplification process has been investigated as a possible mechanism in the generation of a certain type of VLF emission in the exosphere by Gallet and Helliwell<sup>2</sup> and further investigated theoretically by Dowden<sup>3</sup> in great detail. These workers considered the equality  $v = u_0$  as the condition for VLF emission signal amplification, where  $v$  and  $u_0$  are the phase velocity of the electromagnetic wave and the average beam velocity respectively. However,

it should be pointed out that the synchronism condition  $v = u_0$ , as the condition for amplification, is valid only under the special assumption that the electron plasma frequency of the beam,  $\omega_p$ , is much smaller than the angular frequency,  $\omega$ , of the electromagnetic wave, i.e.,  $\omega_p \ll \omega$ , which is usually true in the case of a laboratory TWT, but is not generally satisfied in the case of ionospheric phenomena such as in whistler-mode propagation. The above-mentioned condition of wave amplification has been reexamined under general circumstances within the framework of a one-dimensional, small-signal, single-velocity beam theory. The "forbidden" and "permissible" regions for wave amplification in the system-parameter space has been determined from the determinantal equation of the system. Subsequently the necessary condition for wave amplification has been derived. The investigation reveals that wave amplification is possible even if the value of  $\Omega_0 = (\omega_p/\omega)$  is not small compared with unity, provided that the value of  $B = (v/u_0)$  is in the proper range. It is also shown that the synchronism condition  $B = 1$  does not automatically imply wave amplification since in order to have wave amplification the value of  $\Omega_0$  must also be in a proper range. Furthermore it is shown that at  $B = 1$ , there are two ranges of value of  $\Omega_0$  over which wave amplification may be possible; one lies in the range  $\Omega_0 \ll 1$  and the other lies in the range  $\Omega_0 > 1$ . In the former range it is the forward propagating wave that is amplified which is the case of a laboratory TWA, whereas in the second range it is the backward propagating wave that is amplified which is likely to be the case for ionospheric phenomena.

3.2 Development of a Large-Signal Analysis. Based on a one-dimensional, nonrelativistic theory, a method of analysis has been developed for the study of large-signal interaction between an electromagnetic wave propagating along a slow-wave structure and a multiveloc-

electron beam. The basic interaction equation obtained with the aid of the collisionless Boltzmann equation and Poisson's equation is given in the form of a set of nonlinear, differential equations governing the electric scalar potential function of the slow-wave structure and the electron beam. The present method is based on the concept of a collective interaction between the electron beam and the electromagnetic wave. Under small-signal conditions, it permits the interpretation of interactions between space-charge waves and electromagnetic waves and the interaction phenomenon is observed in a moving frame of reference. The applicability of this method of analysis to the VLF emission by a traveling-wave amplification process is to be considered in a future report.

#### 4. Propagation of Naturally-Occurring Radio Noise Through the Ionosphere

Attention has been focused currently on the derivation of a general, nonlinear, dispersion relationship from Maxwell's equation and Boltzmann's equation for a system consisting of an electromagnetic wave propagating in a relatively cold plasma pervaded by an external magnetic field and gyrating electrons in a stream which penetrates the cold plasma. There are no significant results to be reported at this time.

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3. Dowden, R. L., "Theory of Generation of Exospheric Very-Low-Frequency Noise (Hiss)", Jour. Geophys. Res., vol. 67, pp. 2223-2230; June, 1962.